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P.A. Strakey (PRSA), "Assessment of Multiple Scattering Errors of Laser Diffraction Instruments"
(abstract only)

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Int'l Conf. on Liquid Atomization & Spray Systems **(Statement A)**
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Assessment of Multiple Scattering Errors of Laser Diffraction Instruments

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Characterization of high-pressure rocket injector sprays often involves using commercial laser-based diagnostic instruments to measure droplet size in an environment well beyond the intended range of the instruments. Even in cold-flow measurements, this environment often involves very large number densities of droplets ($N > 10^4$ cc^{-1}) as well as refractive index gradients in the surrounding gas. As a result, optical attenuation and multiple scattering of the probe beam(s) and scattering signal is often the limiting factor in the ability to extract useable data.

Several experimental studies on multiple scattering errors have been reported previously using optically thick suspensions of particles. Most of these studies were limited to relatively small particles (< 150 μm) and either monodispersed or narrow particle size distributions. Hamidi and Swithenbank investigated bi-modal size distributions of glass beads with a maximum size of 105 μm.[1] They found significant errors in measured mean size and proposed an analytical correction factor that could be applied to two-parameter size distributions. Gulder carried out a similar study reporting multiple scattering effects on Sauter mean diameter.[2] He proposed a correction scheme using a model-independent analysis that was validated for D_{32} up to 100 μm. Dodge simulated a dense spray environment using a linear array of nominally identical atomizers with a maximum D_{32} of about 20 μm.[3] His findings showed that the correction scheme developed by Hamidi and Swithenbank greatly reduced the error in D_{32} at transmissions as low as 5%, but did not fully compensate for the effects of multiple scattering. More recently, Harvill *et al.* reported results for suspensions of aluminum oxide particles with a volume median diameter of 50 μm.[4] They found that without a correction, the error in measured volume median diameter was a much as 40% at a transmission of 5%. They also demonstrated the validity of a statistically based correction scheme that did an excellent job of correcting for multiple scattering effects.

Liquid bi-propellant rocket injectors often generate large, non-spherical droplets as a result of the relatively low injection velocities and high chamber back-pressures which create high deformation stresses on the droplet. The goal of this study is to assess the capability and limitations of the laser diffraction technique in dense sprays typical of rocket operating conditions. This involves a relatively broad range of sizes from tens of microns to nearly a millimeter in diameter.

Experimental Setup

In this study, two commercial laser-diffraction instruments were tested. The first was a Malvern 2600c Master Sizer system and the second was a Malvern SprayTech instrument. In order to assess the accuracy and limitations of the two instruments, it was necessary to simulate the dense spray environment with a two-phase medium of known particle number density and distribution. This was accomplished using a dispersion of solid, spherical polystyrene microspheres and distilled water in a magnetically stirred glass test cell.

Separate experiments were conducted with each instrument using both monodispersed microspheres at concentrations ranging from 90% to 1% transmission and sizes ranging from 30 μm to 650 μm. Experiments were also conducted with polydispersed mixtures of beads over the same range of concentrations and sizes. The polydispersed mixtures consisted of six different bead sizes in relative concentrations that approximated lognormal size distributions typical of large-scale rocket injectors.

Results and Discussion

Results from the polydispersed experiments are presented as a percent error in the volume-weighted volume mean diameter, D_{43} from the actual size. D_{43} was chosen as a representative indicator of accuracy

because both instruments use a process of inverting the light scattering data to obtain a particle volume distribution and are thus geared toward providing maximum accuracy in a volume mean diameter. Figure 1 contains plots of measurement error, expressed as a percentage of D_{43} as a function of transmission for each instrument for the polydispersed bead mixtures. In both cases, the multiple scattering correction option has been used. The Spraytech instrument (Fig. 1(a)) showed good accuracy over the range of transmissions studied here. The instrument was accurate to within +/- 10% in the transmission range of 90% to 2%, which is the stated lower range of the instrument. The instrument produced reasonably good results even at a transmission of 1%. The minimum error occurred at about 60% transmission for all the distributions measured.

The results from the 2600c instrument (Fig. 1(b)) were not as encouraging. Even with the multiple scattering correction, the measured D_{43} began to drop significantly below a transmission of about 10%. At a transmission of 2% the measured D_{43} was found to be less than the actual D_{43} by as much as 45%. This is consistent with the fundamental problem of multiple scattering in which the overall angle of light scattering increases with each scattering event. Since scattering angle is inversely proportional to particle size, the increase in overall scattering angle results in a smaller measured size. The multiple scattering correction algorithm used by this instrument did not fully compensate for this effect, however, it did greatly improve the accuracy over using no correction at all. This result is consistent with the findings of Dodge who found that even with the correction, the instrument under-estimated mean size by as much as 20% at a transmission of about 5%.

The disparity in Fig. 1 can be explained by the differences in the multiple scattering correction schemes employed by the two instruments. The 2600c uses a relatively simple analytical correction model while the algorithm used in the Spraytech instrument is based on a statistical approach. The statistical approach requires fewer assumptions at the expense of increased computational complexity.

In terms of dense spray measurements, the limiting factor for the 2600c instrument appears to be the multiple scattering correction which is reliable only to about 10% transmission for the conditions studied here. For the SprayTech instrument, the accuracy is limited by signal-to-noise errors that become significant below about 2% transmission. The instrument is still useable however down to a transmission of about 1%.

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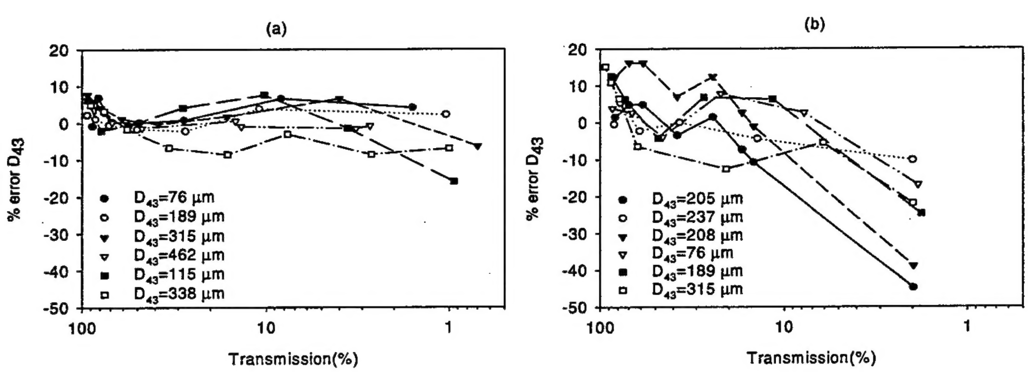

Figure 1: Percent error in measured D_{43} verses transmission for (a) SprayTech and (b) 2600c instruments.